On the wakes behind series of disks in axial configurations

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Abstract

The present study takes a view and clarifies findings of our laboratory tests of the flow fields in wake generated by series of disks (from one to four disks) with varying of distance L_x between disks. Experiments were carried out in water flume ($Re = 1.76 \cdot 10^5$) and compared with results obtained in wind tunnel ($Re = 1.76 \cdot 10^4$). Numerical calculations for water flume experimental conditions using the ANSYS Fluent software were performed. The limit number of disks in the wake behavior for repeating elements was found. However, the difference between the decay of a deficit of axial velocity for different L_x was insignificant as compared with the difference between the wakes behind a pair of disks and a single disk. The deficit level decreases with increasing of flow turbulence level of oncoming stream was showed.

1 Introduction

Within the investigation of bluff body aerodynamics, the investigation of the interaction between wakes in multiple body configurations is of particular interest. It draws attention when assessing the wind loads on the repeating elements in the construction of bridges, buildings, chimney pipes, and other civil facilities. The similar sets of repeating samples can be useful for solving various engineering problems. In this regard, the study of wake behind series of identical thin disks is an important and interesting problem for the mentioned applications.

Today, there are many works devoted to the study of the formation and evolution of the near and far wake behind a circular disk at low Reynolds numbers, as this is of interest, both from a theoretical and practical point of view. In the range of Re numbers from 115 to 1000 in the work Yang et al. (2014), using the numerical approach of LES, it was shown that with an increase in the Reynolds number behind the disk, three types of instabilities are formed, such as natural vortex shedding, shear-layer instability and a very low frequency instability. For higher Reynolds numbers from $1.5 \cdot 10^4$ to $3 \cdot 10^5$, the existence of these three types of near-wake instability was experimentally demonstrated in Berger et al. (1990). At the moment there are very few works devoted to the study of the behavior of the vortex wake behind both one and the combinations of coaxial disks in the turbulent flow regime. One of the most recent papers Tian et al. (2016) devoted to a numerical study of the flow past a disk at Re=$1.5 \cdot 10^5$. The recent nature of these studies suggests that the direction of the study of wake behavior behind disks combinations in the turbulent flow regime is an actual research direction. The present experimental investigation extended results of the near and far wake data for three or four elements.

2 Experimental setup

The present work takes a view and clarifies findings of our laboratory tests of the flow fields in wake generated by the interactions of the disk-disk-disk-disk (D-D-D-D), disk-disk-disk (D-D-D), disk-disk (D-D) and single disk (D) in the water flume of length 35 m, width 3 m and height of about 0.9 m with flow rate of 1.5 m³/s (fig. 1) and in the open loop wind tunnel with turbulence level less than 1%. The free

stream velocity in the test section was about $U_0 = 0.565$ m/s with the uniform profile outside the boundary layer thickness (0.2 m) and the small level of turbulent pulsations (~ 4 %). A plexiglas disks of the diameter D=300 mm and thickness h=10 mm were used as the passive elements. The Reynolds numbers based on disk diameter and the initial flow conditions in the flume vary in the range $1.4 \cdot 10^5 < Re < 2.4 \cdot 10^5$ Naumov et al. (2016), Okulov et al. (2016), and Okulov et al. (2017). All disks configurations were investigated for interspatial distance $L_x = 3$-$7D$ along the axis of the setup which is mounted on a platform displaced along the flume.

In addition, the measurements of velocity deficit attenuation behind one disk (D) were carried out using an LDA system in the small wind tunnel. A disk of the diameter D=25 mm and thickness h=2 mm were used. The dimensions of the test section were 2 m in length, 0.2 m in width and 0.2 m in height. The velocity of the oncoming air flow was $U_0 = 10.6$ m/s.
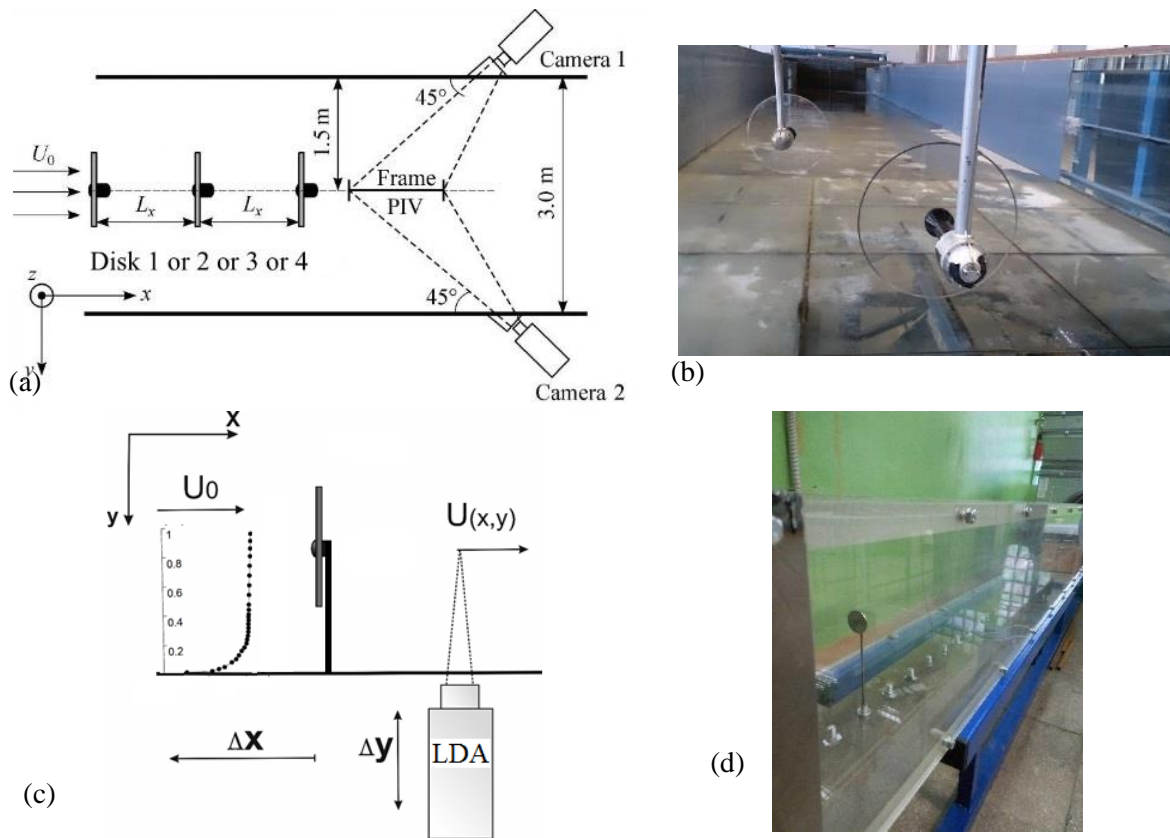
Figure 1. Experimental setups: in the water flume (a, b) and in wind tunnel (c, d).

3 Numerical methods

Numerical simulation in order to study the formation and attenuation of the axial velocity deficit behind both the one and the combination of the same type of elements (disks) under coaxial arrangement, streamlined by a uniformly approaching flow with a deterministic level of turbulence was carried out. The RANS method in a stationary setting as a numerical approach to the modeling of turbulent flow was used and the two-parameter turbulence model SST k-ω (Shear-Stress Transport) to close the system of equations was used. For the numerical solution the PISO (Pressure-Implicit with Splitting of Operators) pressure-velocity coupling scheme was applied. Computations with the use of CFD package ANSYS Fluent have been carried out.

The computational domain is a cylindrical channel that is presented in Fig. 2. The input and output boundaries are located at a distance of $4D$ and $10D$ respectively from the disk. The cross-sectional diameter of the computational domain was equal to $10D$. The diameter and thickness of the disk

corresponded to the values that were used for the experimental measurements in the water flume, and were equal to 300 mm and 10 mm, respectively. The Cartesian coordinate system (x, y, z) was used and the origin of the coordinate system was located in the center of the front wall of the disk. The x axis was directed in the direction of flow.

In a numerical study of the flow past the combinations of disks D-D, D-D-D, D-D-D-D the input boundary was located $4D$ from the first disk and the output boundary was located $10D$ from the last disk. The characteristic distance between the disks was chosen $L_x = 3D$.

At the inlet to the computational domain, the velocity of the oncoming flow U_x=0.565 m/s, U_y=0, U_z=0 was assigned which corresponds to the Reynolds number U_xD/v =1.76·10^5 calculated from the diameter of the disk. At the outlet and the sides of the computational domain, the non-reflecting boundary condition is used. The disk surface is treated as a non-slip boundary. A three-dimensional computational grid was generated by rotating a two-dimensional non-uniform mesh around the axis of the disk x. The angle of the partition was 5°, and the number of layers 72. The total number of elements for the combinations of disks D, D-D, D-D-D, D-D-D-D with a distance between them $L_x = 3D$ was 3.29·10^6, 4.49·10^6, 5.59·10^6, 6.69·10^6.
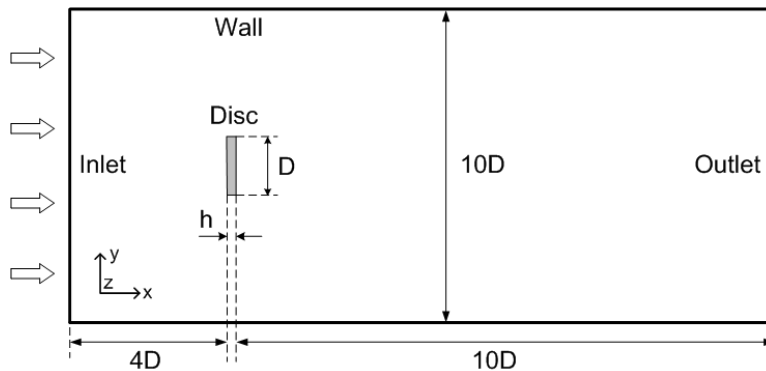

**Figure 2.** Schematic of the computational domain.

4 Results and discussion

4.1. Experimental measurements

For configuration with two elements the difference in the wake behavior for the disk and disk-disk systems were found in Naumov et al. (2016). The present experimental investigation extended results of the near and far wake data for three or four elements. The wake intensity grows for the dual disks in comparison with the single one (see Fig. 3). The value of the maximal velocity deficit in a wake behind the pair of two disks was larger than in the wake behind a single disk. However, the difference between intensity of a far wake for different distances between the disks (L_x) was insignificant as compared with the difference between the wakes behind a pair of disks and a single disk. It confirms that the turbulence level of the oncoming flow effect on velocity deficit. It can be seen from the Fig.3, the velocity deficit decreases with decreasing the number of disks. We approximate dependence of velocity deficit on distance x/D by the formula of the G-model determined as $a·(x-x_0)^{-2/3}$, where a and x_0 are determined by the type of the bluff body Johansson et al. (2003), and velocity deficit $\Delta U=U-U_0$. For the single disk these parameters have been identified as $a = 0.31$ and $x_0 = 3.2$, then for a pair of disks with $L_x = 4D$, $6D$ and $8D$, these coefficients take other values, very close to each other, which can be approximated by the average curve at $a = 0.49$ and $x_0 = 2.1$. Therefore, these results have a good agreement with far wake characteristics of the previous work Okulov et al. (2017).
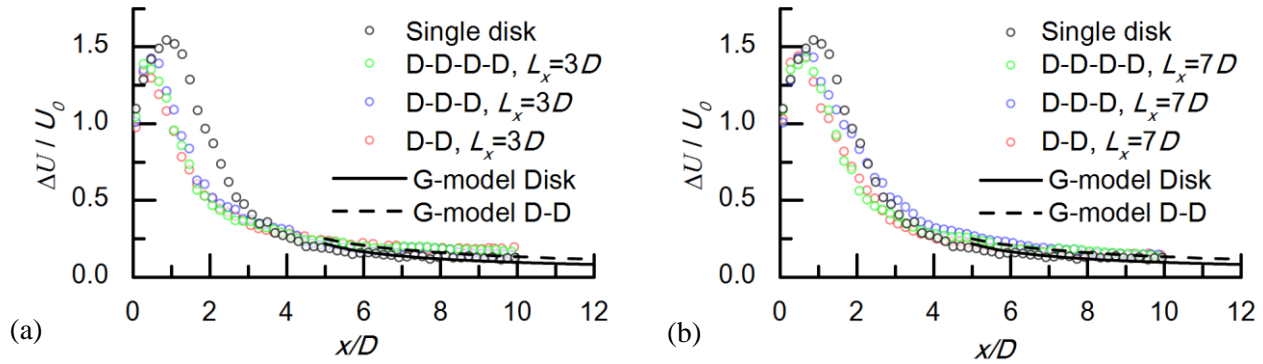
Figure 3. Left - near wake behind single disk (D) and disk-disk (D-D) configuration by PIV, Right - development of the velocity deficit of the different configurations for distance between disks $L_x=3D$ (a) and $L_x=7D$ (b) ($x=0$ on the latest disk).

Figure 4 shows the distribution of the averaged axial velocity deficit in air and water test facilities. Reynolds numbers were $1.76 \cdot 10^5$ and $1.76 \cdot 10^4$, respectively. Turbulence level was equal 4% for both work mediums(water and air). The results showed that with a decrease in the Reynolds number for the case of a single disk flow, faster deficit of the velocity deficit in the far wake upstream occurs.
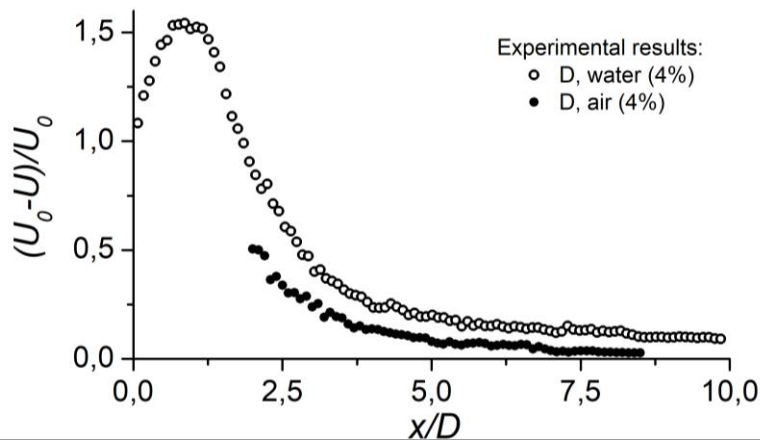
Figure 4. The decay of axial velocity component deficit behind single disk for experimental conditions of the water flume and the wind tunnel.
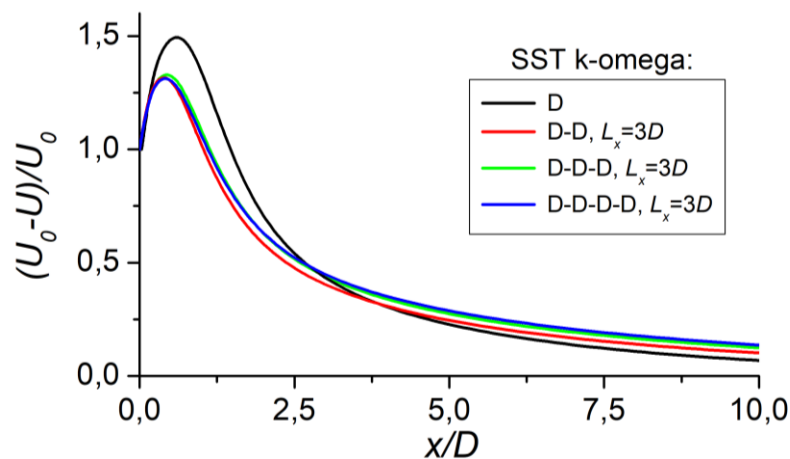
4.2. Numerical simulation

A numerical calculation was carried out using the SST k-ω model aimed at studying the effect of the deterministic turbulence level of a uniform oncoming flow on the resulting distribution of the axial velocity deficit in the wake behind the single disk. Fig. 5 shows the calculated deficit distributions of the axial velocity component along the channel axis x for different turbulence levels of 4, 10, and 20%. The velocity was normalized with the free stream velocity U_0 and the distance along the x axis with the disk diameter D. From the presented graphs, it is seen that behind the disk there is formation of a recirculation zone. The higher the level of turbulence of the free stream leads to shrinking of the recirculation zone, and behind this zone the axial velocity deficit monotonically decreases in the wake. Comparison of the experimental data obtained in water flume at a level of turbulence of the oncoming stream of 4%, with the results of numerical simulation, showed that a similar law of the change in the rate deficit for one disk is achieved in the simulation at 20%. These results show that an increase in the level of turbulence significantly affects the rate of reduction of the velocity deficit in the far wake.
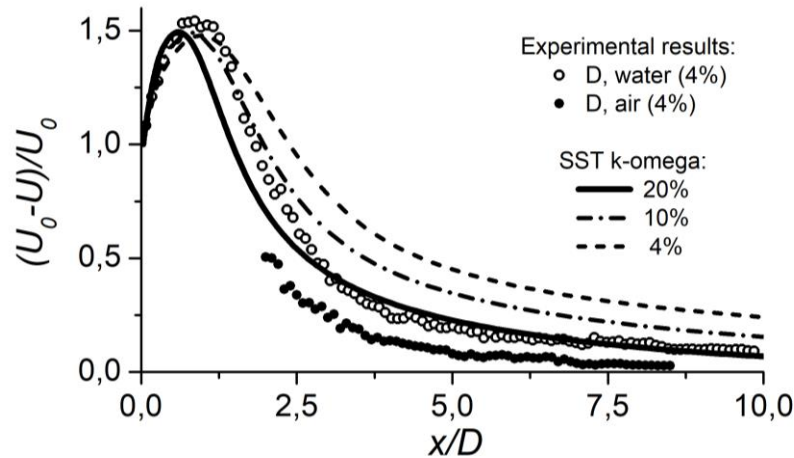
Figure 5. Comparison of experimental and numerical results and influence of turbulence level of oncoming free flow on the maximal deficit of the axial velocity for the case of a single disk.

Performed numerical simulations were showed the effect of combinations of disks D-D, D-D-D, D-D-D-D with the selected distance between disks $L_x = 3D$ on the formation and decay of the wake. Taking into account the fact that the experimental dependence for one disk is obtained in numerical calculation at 20%, all further results are obtained for a given level of turbulence. Figure 6 shows the results of numerical modeling of the vortex wake attenuation behind the combinations of coaxial disks using the SST k-omega turbulence model. The results showed that with an increase in the number of disks in the channel, the rate of reduction of the axial velocity deficit in the far wake.

Figure 6. Comparison of the axial velocity deficits obtained with numerical simulation for combinations of disks D, D-D, D-D-D, D-D-D-D with a distance between them $L_x = 3D$.

4 Conclusion

The present study takes a view and clarifies findings of our laboratory tests of the flow fields in wake generated by series of disks (from one to four disks) with varying of distance between them L_x. The difference between the decay of a deficit of axial velocity for different L_x was insignificant as compared with the difference between the wakes behind a pair of disks and a single disk. The increasing in the number of disks does not a significant influence on the wake, but increasing the distance between disks more than $7D$ lead to convergence of the deficit curves to the single disk case. The deficit level decrease with increasing of flow turbulence level was showed with using of numerical simulation.

Acknowledgements

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